

Hydrologic Modeling System (HEC-HMS) What's New

First European HEC Software Workshop

25 – 26 October 2016

London, UK

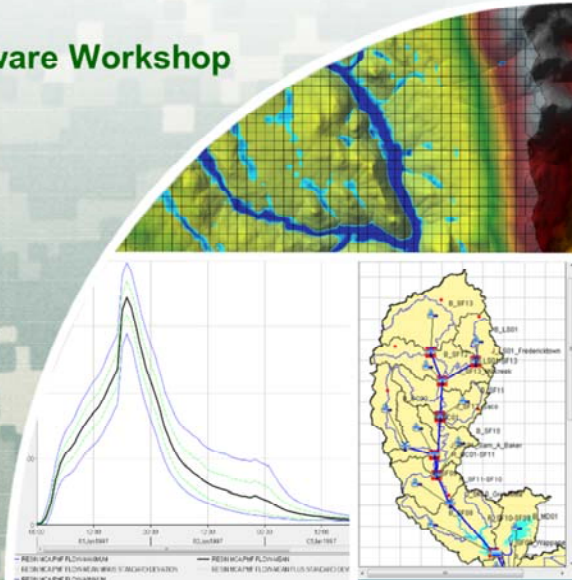
Matthew Fleming, P.E.

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Hydrologic Engineering Center

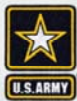


US Army Corps of Engineers
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Overview

- **Newer Capabilities in HEC-HMS Version 4.2**
 - ▶ Monte Carlo Simulation
 - ▶ Computational Efficiencies
 - ▶ Flood Forecasting Tools
- **Capabilities Under Development for HEC-HMS Version 4.3 and Beyond**
 - ▶ GIS Tools for Subbasin and Stream Delineation
 - ▶ Markov Chain Monte Carlo Optimization/Simulation
 - ▶ Variable Unit Hydrograph and Routing Options
 - ▶ Two-Dimensional Flow and Sediment



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HEC-HMS Development Team

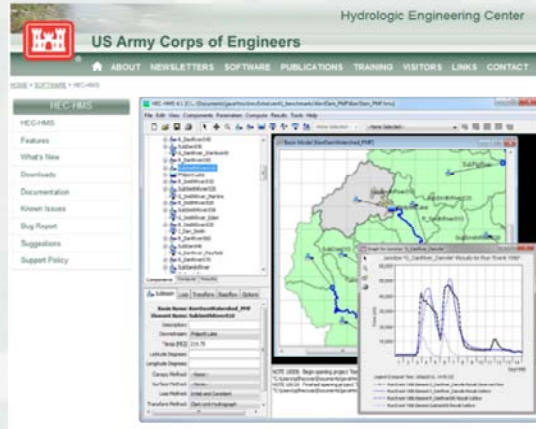
- Bill Scharffenberg - Lead developer and project lead
- Mike Bartles - Technical support, testing, and applications
- Tom Brauer - Technical support and software development
- Alex Sanchez - Software Development
- Matt Fleming - Technical support and testing

- HEC-HMS Functionality within CWMS/HEC-RTS
 - ▶ Fauwaz Hanbali, Bill Charley, and Tom Evans
- Contractors
 - ▶ Paul Ely and Brian McCormick
- USACE Collaborators
 - ▶ Elke Ochs and Brian Skahill



HEC-HMS Webpage

- <http://www.hec.usace.army.mil/software/hec-hms/>
- Download software
- Download manuals
 - User's Manual
 - Technical Reference Manual
 - Application Guide
 - Quick Start Guide
 - Validation Guide
- Submit bug reports
- Upcoming training

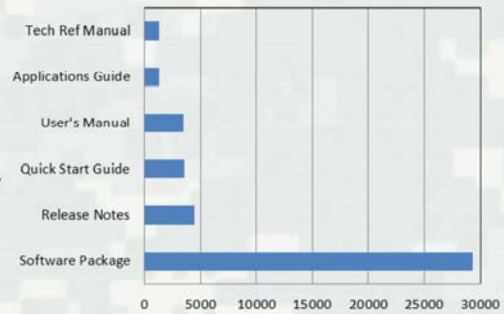


Completed Products

- HEC-HMS Version 4.1

- ▶ Production release until 24 Aug 2016.
- ▶ First release of the uncertainty analysis with classical Monte Carlo sampling.
- ▶ Product downloads are shown for FY16 year-to-date.

2016 HEC-HMS 4.1 Product Downloads



- HEC-HMS Version 4.2

- ▶ Released on 25 Aug 2016.



Available Training Classes

- Hydrologic Modeling with HEC-HMS
- Advanced Applications of HEC-HMS
- H&H for Dam Safety Studies



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HEC-HMS Program Scope

- Designed to simulate watershed hydrology.
 - ▶ Surface water modeling.
 - ▶ From meteorology to watershed outlet.
- Tool kit of options.
 - ▶ Generalized modeling.
 - ▶ Mathematical model choices.
 - ▶ Analysis tools.
- Graphical user interface
 - ▶ Map of the watershed.
 - ▶ Point-and-click for entering and updating data.
 - ▶ Graph and table displays of simulation results.



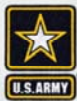
The program is designed for surface water hydrology simulation. It includes components for representing precipitation, evaporation, and snowmelt; the atmospheric conditions over a watershed. It includes infiltration, surface runoff, and baseflow over the land surface. It includes stream flow with possible percolation losses below the channel. Basically it includes all of the different components of the hydrologic cycle.

The program can be adapted to fit almost any watershed; it is not limited to just one custom watershed or a certain class of watersheds. For each component of the hydrologic cycle, we provide multiple choices. Some of those choices are better suited to different types of watersheds. The job of the user is to select the best choices for their watershed, and then enter the appropriate parameter values. The values will be things like areas, river lengths, soil properties, etc. These parameters adapt the model to represent a particular watershed. The program does the hard part of matching all the selections by the user together into a single, comprehensive model of the watershed. It also does the tedious work of solving the differential equations behind each selection in order to compute results. It then provides analysis tools, such as statistical summaries to better understand the results.

All of the capabilities of the program are controlled by a nice graphical interface that we think is pretty easy to use. The watershed is represented with a map that shows all of the modeling components plus background maps for spatial orientation. Clicking on any item in the program immediately shows the parameter data for it so it can be edited. Plenty of graphs and tables are provided for visualizing results in helpful ways.

HEC-HMS Project

- Container for main components.
 - ▶ Basin model.
 - ▶ Meteorologic model.
 - ▶ Control specifications.
- Also holds additional components.
 - ▶ Time-series gages.
 - ▶ Paired data functions.
 - ▶ Grid data sets.
- Provides analysis tools.
 - ▶ Parameter estimation using optimization theory.
 - ▶ Depth-area analysis for frequency storm.
- Subdirectory name

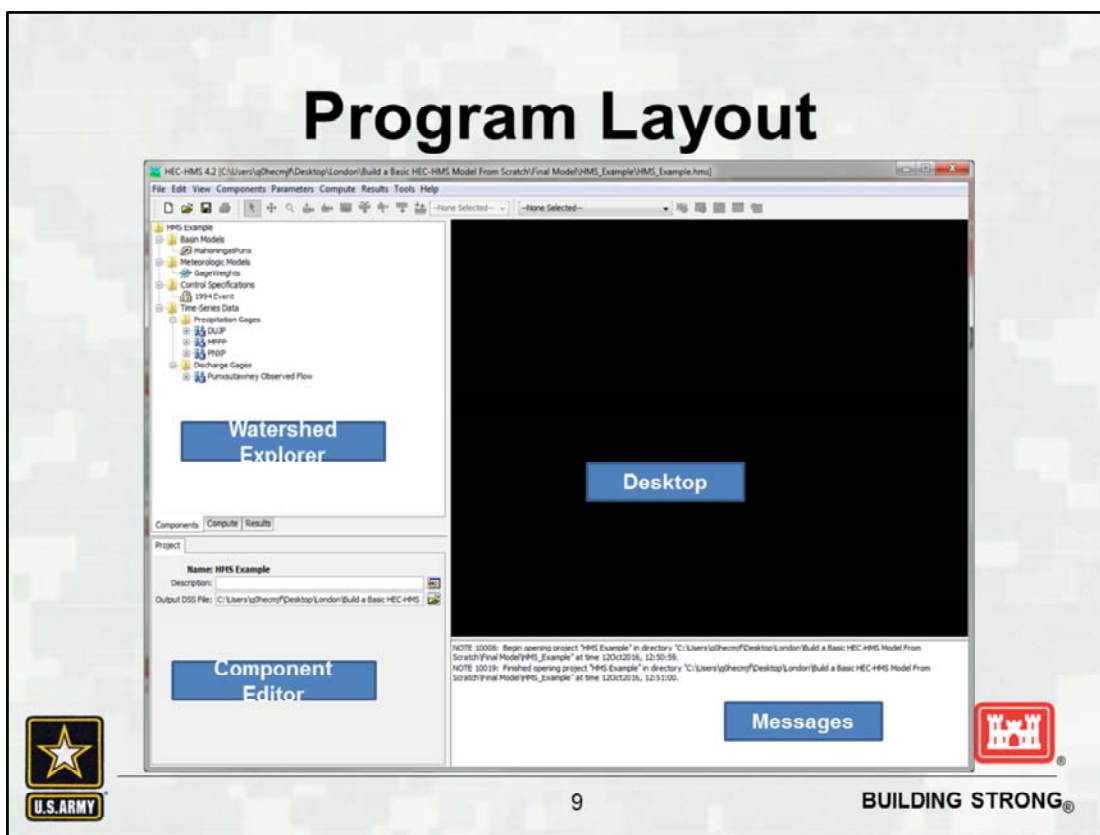


Basin models, meteorological models, and control specifications are all main components used in simulation runs. The primary time-series gages are precipitation and discharge; others used less often include temperature and solar radiation. A paired data function is simply a relationship between a dependent and independent variable; for example, storage-discharge curves or rating curves. Also included in paired data are cross sections and annual patterns. Annual patterns are used for some special parameters that change value during the year, but use the same pattern for every year. Grid data can be boundary conditions like precipitation with a separate grid for each time interval in a time window, or they can be parameters like hydraulic conductivity.

Analysis tools are things that provide added value to simulations. That is, they start from a simple simulation run and then do additional processing. We will be adding more analysis tools in future versions of the program.

A project is stored in a directory on the file system. It can be created anywhere the user has permission to read and write, whether on the local computer or on a network share. When transferring a project the entire directory and its subdirectories should be sent.

Program Layout



This is the new interface first introduced with Version 3.0.0 in December 2005. Clicking on an item in the Watershed Explorer will load that editor in the bottom left Component Editor area, and if possible highlight it in the basin map (for hydrologic elements only). The Desktop area holds the basin map, global editors, and results. Any messages that are generated are scrolled continuously in the Message Log area.

The first tab (Components) of the Watershed explorer holds all of the different types of data in a project. The second tab (Compute) holds simulation items including simulation runs, optimization trials, and depth-area analyses. The third tab (Results) provides access to any time-series or summary result produced by all simulation items.

Data Management

- Configuration data and parameters.
 - ▶ Files within the project directory.
 - ▶ Automatically created, saved, loaded, etc.
- Data Storage System HEC-DSS.
 - ▶ Time-series and paired data can be manually entered or retrieved from external files.
 - ▶ Grid data can only be retrieved from external files.
 - ▶ All time-series results computed during a simulation are stored.
- Automatic data handling.
 - ▶ Units conversion.
 - ▶ Interpolation or accumulation.



Data files are automatically added to the project directory as the user creates components and saves them. For example, there is a separate file for each basin model, meteorological model, and control specifications. There is one file that holds all of the time-series gage information, one file that holds all of the paired data information, and one that holds all of the grid data information. Additional files are added to the project directory for other features as well. The user never needs to look in this files and should not edit the content.

DSS is central to the operation of HMS, but users do not need to be "experts" in DSS by any means. Any time-series or paired data entered manually by the user is internally stored in a special DSS file in the project directory. Edits made by the user are automatically updated in the DSS file. Gage and paired data can also be retrieved from DSS by specifying a file and selecting a pathname. Because grid data is so complex, it cannot be entered manually but must be retrieved from a DSS file. All time-series results during a simulation are stored in a DSS file and this is also how the program passes data internally. The results stored here can be used with other HEC products. Information in the User's Manual chapter 4 and appendix A explains the convention for pathnames.

Basin and meteorological models can be switched between U.S. customary and metric units. When switched, all parameter data is automatically converted between unit systems. Gages, paired data, and grid data each have their own unit system that can be what ever is most convenient. If a gage uses metric units but a basin model uses U.S. customary units, then a conversion happens automatically. Gage data is automatically interpolated if the simulation time interval is less than the data interval. Accumulation also happens automatically is gage data is at a shorter time interval than the simulation interval.

Main Components

- Basin model gives the physical description of the watershed.
 - ▶ Subbasin: watershed catchments where rain falls.
 - ▶ Reach: rivers and streams.
 - ▶ Reservoir: dams and lakes.
 - ▶ Junction: confluence.
 - ▶ Diversion: bifurcations and withdrawals.
 - ▶ Source: outflow from another model or springs.
 - ▶ Sink: outlets and terminal lakes.
- Meteorologic model describes atmospheric conditions over the watershed land surface.
 - ▶ Shortwave and longwave radiation.
 - ▶ Precipitation.
 - ▶ Potential evapotranspiration.
 - ▶ Snowmelt.
- Control specifications: Time control during a simulation run.

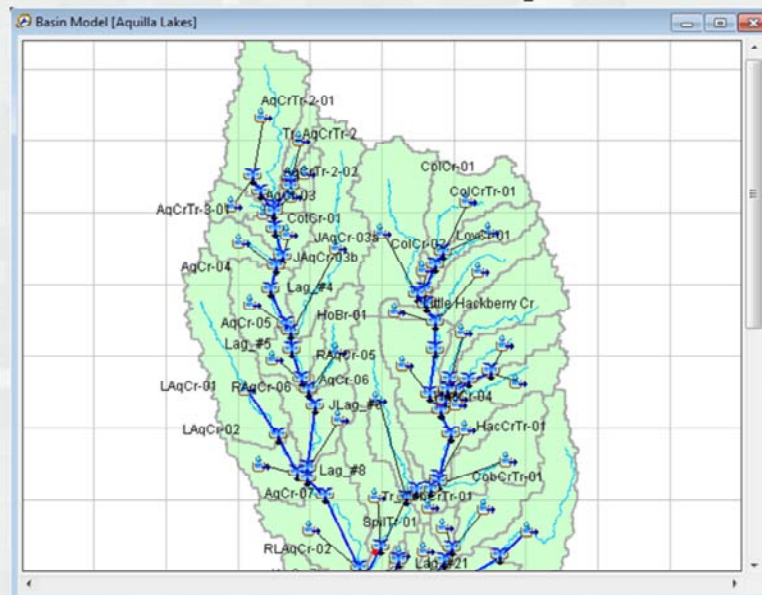


The basin model is where users spend most of their time. This is where the stream network is defined. Subbasins are the only elements that receive precipitation and other meteorological inputs. They are broken into segments for infiltration (loss rate), surface runoff (transform), and subsurface return flow (baseflow). Reaches represent the movement of water in an open channel. Reservoirs can be used for either natural lakes or man-made dams; anything that impounds water. Junctions are a convenient way to show where multiple streams come together. Diversions are used lateral weirs, pumps stations, or other places where water is removed from the stream; diverted water can be connected back into the stream network at a downstream location. Sources are usually used as upstream boundary conditions when it is inconvenient to include the entire watershed in the basin model. Sinks are just a formal way of terminating a stream network; they are helpful when a basin model needs to contain more than one outlet perhaps because of multiple adjacent watersheds included in the same basin model.

The meteorological model handles all of the atmospheric conditions over the watershed. Precipitation is always required if there is a subbasin, but the other meteorological model elements are optional. Potential evapotranspiration is the upper limit on plant water use based only on atmospheric conditions. Elements within the basin model will use the potential evapotranspiration and then compute actual evapotranspiration based on available water in the soil and possibly other factors. When used, the snowmelt module takes the computed precipitation and determines if it fell in a liquid (rain) or frozen (snow) state. It then tracks the accumulation and melt of the snowpack.

Control specifications are lightweight components. They include the beginning date and time of a simulation, the ending date and time, and the time interval for calculations. Most model elements compute at the time interval specified in the control specifications. However, some elements use adaptive time stepping and may run as short as 1 second intervals. These special elements only record results at the specified time interval.

Basin Map



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The basin map is used to visualize a basin model component. A variety of background map formats can be used including shape files, DXF, and aerial photos. The use of maps is always optional but can be helpful in gaining a spatial perspective to the watershed. Clicking on an element icon with the mouse will highlight it in the Watershed Explorer and display its data in the Component Editor. Only one basin model can be open at a time. You must click on the basin model in the Watershed Explorer for the map to open.

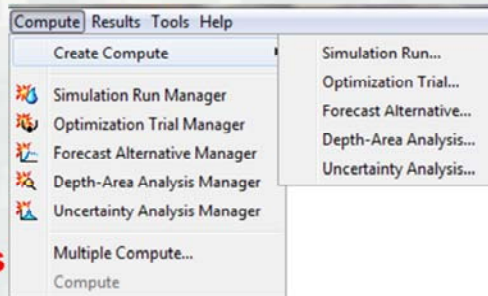
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Newer Features Available in HEC-HMS version 4.2

- List of Compute types:
 - ▶ Simulation Run
 - ▶ Optimization Trial
 - ▶ Forecast Alternative
 - ▶ Depth-Area Analysis
 - ▶ **Uncertainty Analysis**



Hydrologic Modeling Uncertainty

- The Corps of Engineers has a goal of improving transparency of uncertainty in Hydrologic Models.
- Boundary condition uncertainty.
 - ▶ Precipitation data and other atmospheric variables.
 - ▶ Sources of inflow to the watershed.
- Initial condition uncertainty.
 - ▶ Soil moisture, channel baseflow, reservoir pool elevation, and other variables at the start of the simulation.
- Model uncertainty.
 - ▶ Selecting the correct representation of the hydrologic processes that includes relevant details.
- Parameter uncertainty.
 - ▶ Identifying the correct values for the parameters in each process representation.



Modeling frameworks are needed that can capture knowledge uncertainty and natural variability uncertainty.

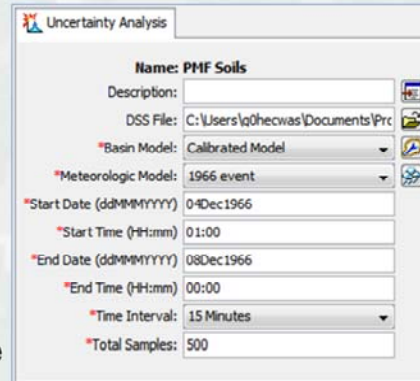
Monte Carlo Technique

- A traditional hydrologic model is deterministic. Given a set of parameters, it will always compute the same result because it does not include randomness.
- HEC-HMS Version 4.2 contains a new Uncertainty Analysis simulation type which uses Monte Carlo sampling of model parameters.
- Assume we can describe the uncertainty in each parameter using a probability distribution function.
- Use a pseudo-random number generator to sample a random value for each parameter.
- Compute the model with sample parameter values and store the important results. Assume each sample is equally likely.
- After a sufficient number of samples, use statistics to estimate key output variables with uncertainty.



HEC-HMS Uncertainty Analysis

- It is a good idea to first create a simulation run and test it. Remember that parameter sampling may generate much larger and lower flows than during the test.
- The Uncertainty Analysis combines a basin model and meteorological model.
- Enter start and end time, and choose a time interval.
- Enter the total number of samples for the Monte Carlo simulation.



The screenshot shows the 'Uncertainty Analysis' dialog box in HEC-HMS. The 'Name' field is set to 'PMF Soils'. The 'Description' field is empty. The 'DSS File' is set to 'C:\Users\q0hec\w\Documents\Proc'. The 'Basin Model' is set to 'Calibrated Model'. The 'Meteorologic Model' is set to '1966 event'. The 'Start Date (ddMMYYYY)' is '04Dec1966', 'Start Time (HH:mm)' is '01:00', 'End Date (ddMMYYYY)' is '08Dec1966', 'End Time (HH:mm)' is '00:00', 'Time Interval' is '15 Minutes', and 'Total Samples' is '500'.



Selecting Distribution Parameters

- Most parameters in the basin model can be selected for analysis:
 - ▶ Canopy, surface, loss rate, transform, baseflow, channel routing, reservoir structures.
 - ▶ Empirical – SCS curve number.
 - ▶ Conceptual – storage coefficient.
 - ▶ Spatial variability – canopy storage.
 - ▶ Scaling – hydraulic conductivity.
 - ▶ Knowledge – culvert coefficients.
 - ▶ Initial conditions – initial soil moisture.
- Optionally, add minimum and maximum limits. Consider these limits carefully because they lead to distribution clipping.

Uncertainty Analysis Parameter 1

Name: PMF Soils Surface

Element: Bear Creek

Parameter: Clark Unit Hydrograph - Time of Concentration

*Method: Simple Distribution

Distribution: Gamma

*Minimum: 10

*Maximum: 50

*Shift: 0

*Shape: 8.0

*Scale: 3.0



Monthly Distributions

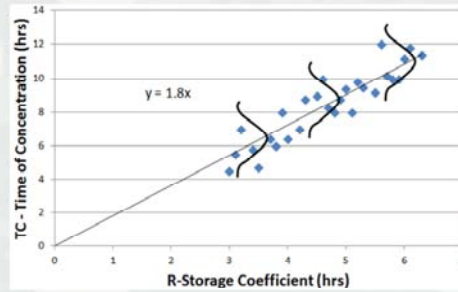
- Choose a distribution function and enter different parameters for each month. For example, a normal distribution with different mean and standard deviation for each month.
- The start time determines which parameters will be used.
- Parameters do not change during the rest of the simulation.
- The best use is for initial conditions that are strongly correlated with season.
- This option supports integration of HEC-HMS into a HEC-WAT FRA simulation where the event date is sampled.

Uncertainty Analysis Parameter 1				
Name: 2004 uncertainty				
Element: Sayers Dam				
Parameter: Outflow Curve - Initial Elevation				
Method: Monthly Distribution				
Distribution: Triangular				
Minimum: 600				
Maximum: 635				
Month	Lower	Mode	Upper	
January	609.36	624.44	628.83	
February	609.34	621.38	624.71	
March	609.43	614.55	626.25	
April	616.71	624.64	629.50	
May	623.21	629.42	630.98	
June	629.14	629.50	630.23	
July	628.89	629.53	630.13	
August	628.41	629.49	629.96	
September	627.99	629.44	630.74	
October	610.41	629.46	629.90	
November	609.25	628.27	629.67	
December	609.30	624.47	627.20	



Regression Plus Additive Error

- Choose an independent parameter that has already been selected.
- Enter the intercept and slope for the relationship to the independent parameter.
- Select a distribution function for the epsilon error term and enter parameters.
- Independent parameter is sampled first and then the regression relationship is applied with error term to compute value for this parameter.
- Useful option for grouping multiple basin elements.



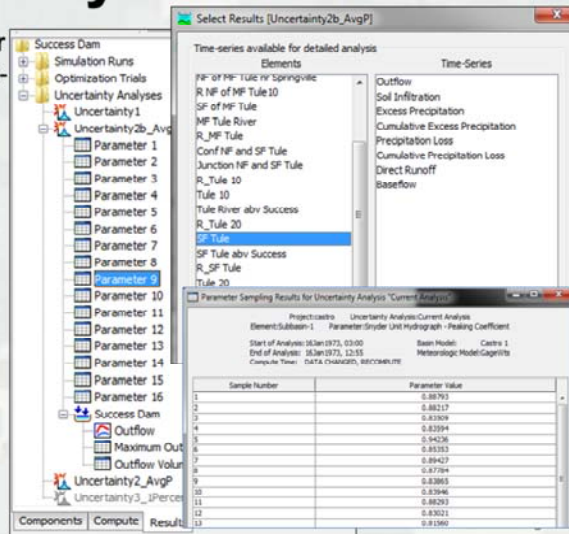
A screenshot of the 'Uncertainty Analysis' software interface. The 'Parameter 2' tab is selected. The settings are as follows:

- Name: Analysis April 1994
- Element: Mahoning Creek Local
- Parameter: Initial and Constant - Constant Rate
- Method: Regression With Additive Error
- Reg Element: E.B. Mahoning Creek
- Reg Parameter: Initial and Constant - Constant Rate
- Regression: Linear
- Slope: 1
- Intercept: 0
- Distribution: Normal
- Mean: 0
- Sigma: 0.2



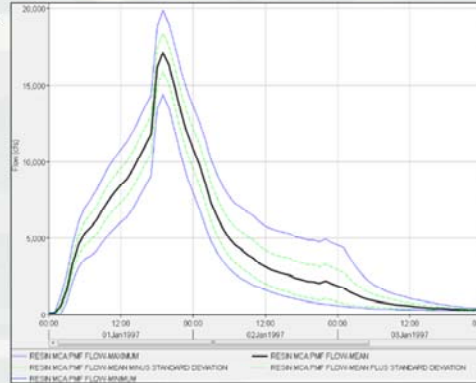
HEC-HMS Uncertainty Analysis

- Model output is only saved at user selected elements, individual time-series records.
- Output results from HEC-HMS include:
 - Sampled parameter values
 - Time-series (mean, ± 1 Std Dev, and min/max) for selected locations
 - Summary information (peak flow per event)
- Time-series data for each realization is stored in the simulation DSS file.
- Additional result plots will be available in future versions.



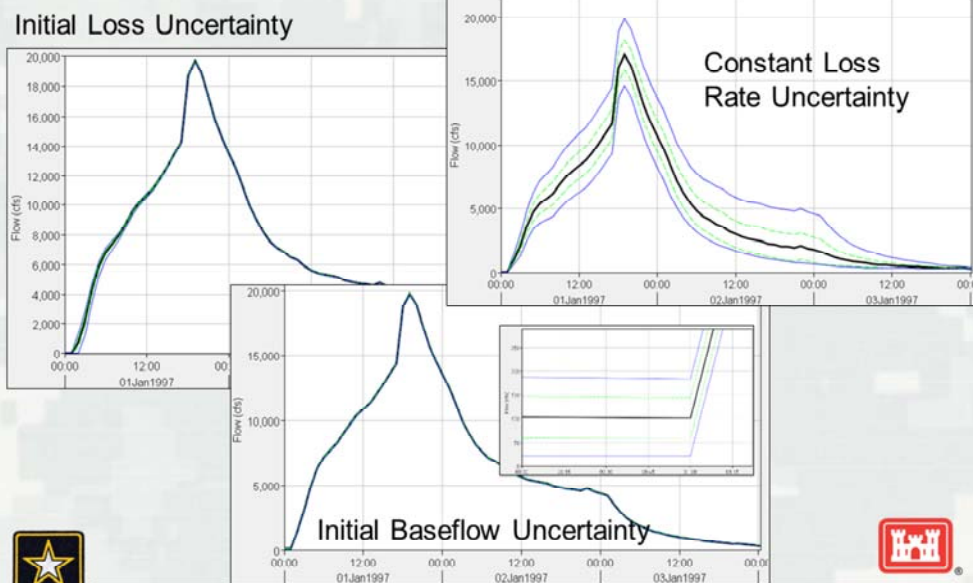
Parameter Uncertainty Example

- An analysis can be quickly configured to better understand the influence of uncertainty from individual parameters on the computed hydrograph.
- Separate uncertainty analyses were developed where each one evaluated a specific model parameter: Initial Loss, Initial Baseflow, and the Constant Loss Rate.
- The uncertainty distribution parameters were “estimated” from model calibration events.
- The figure on this slide shows a MC simulation of a hypothetical flood with uncertainty in all three parameters.



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Parameter Uncertainty Example



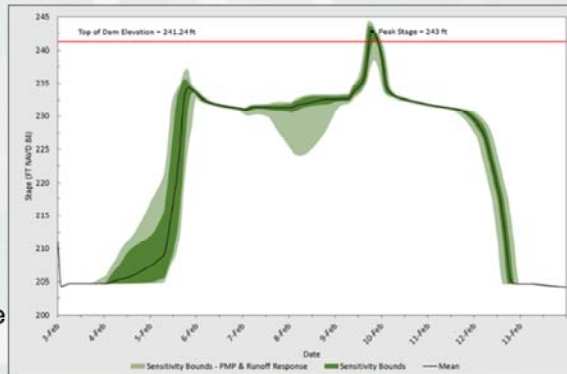
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Example Application

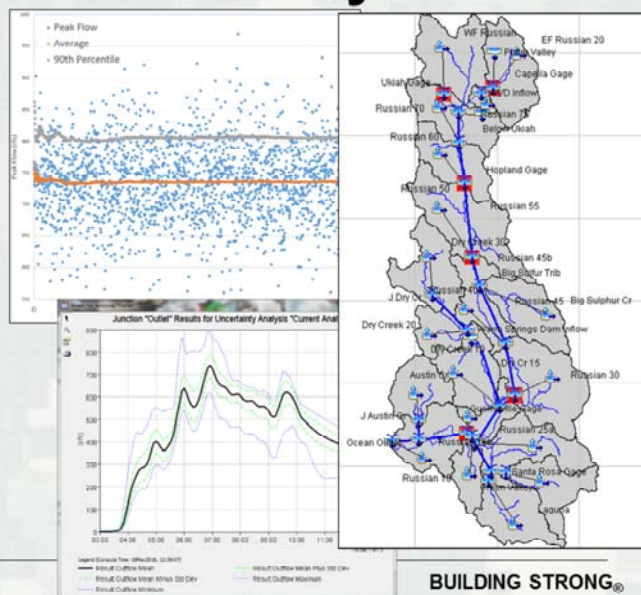
Uncertainty in Design Flood

- A recent study used the uncertainty analysis option to bound the reservoir peak stage estimate given uncertainty initial soil moisture and infiltration parameters.
- The analysis demonstrated that reasonable parameter values were being used in the design, and were not overly conservative.



Future Work on the Classical Monte Carlo Analysis

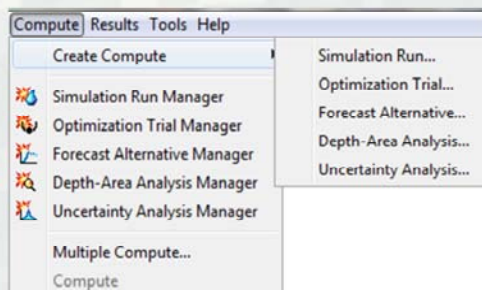
- Add the capability for defining uncertainty distributions on a zonal basis.
- Add convergence criteria for ending the model simulation.
- Improved results plotting.
- Add capability to sample parameters within the meteorological model.



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Newer Features Available in HEC-HMS version 4.2

- List of Compute types:
 - ▶ Simulation Run
 - ▶ Optimization Trial
 - ▶ **Forecast Alternative**
 - ▶ Depth-Area Analysis
 - ▶ Uncertainty Analysis

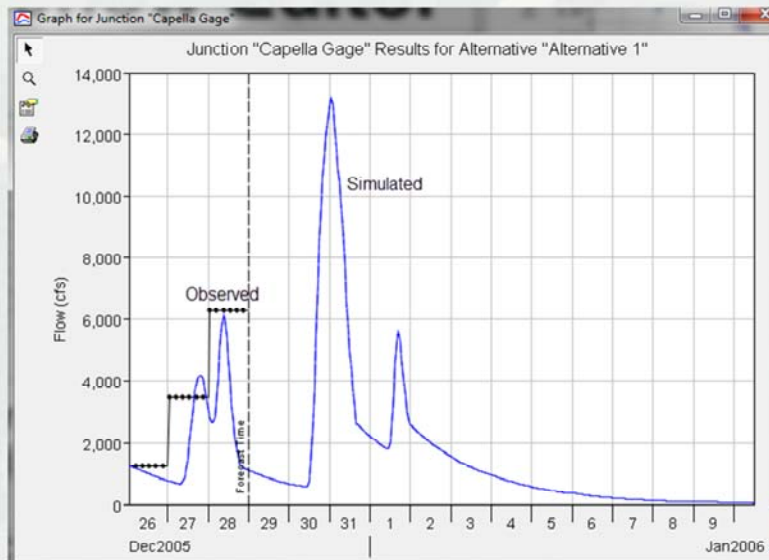


Forecast Alternative

- A *Forecast Alternative* is a different type of simulation run designed to help forecast flow in real-time.
- Select a zone configuration for the loss rate, transform, and baseflow parameters.
- Adjust the parameters in each zone to improve model performance:
 - ▶ New parameter value.
 - ▶ Multiply by a ratio.
 - ▶ Add or subtract an offset.
- Use observed flow to automatically replace computed flow up to the time of forecast.
- Current work is focused on improving performance (reducing compute time) and adding support for interactive calibration.



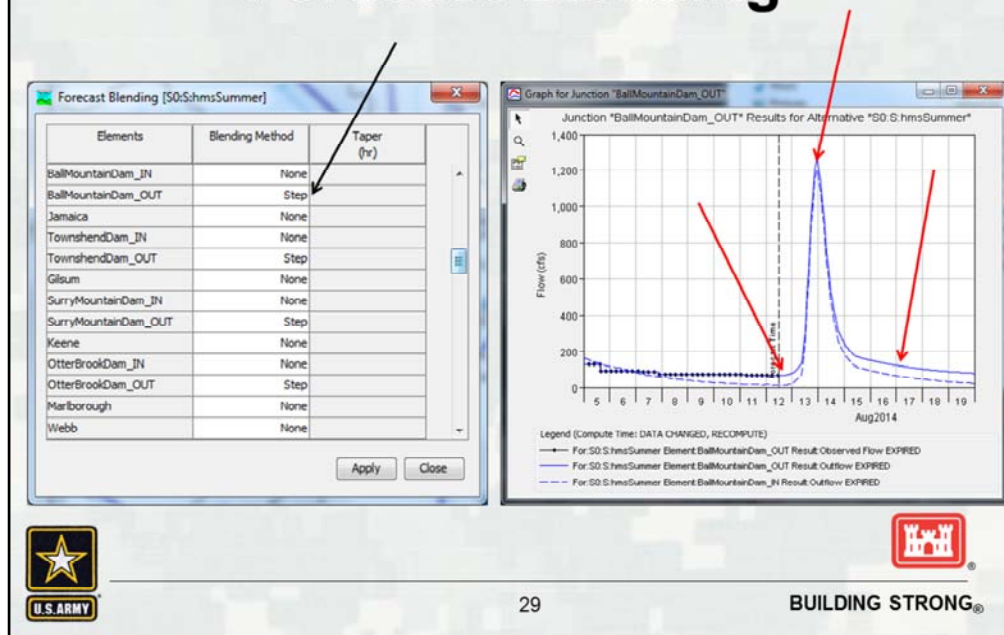
Forecast Alternative



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Forecast Blending



- When "Step" is selected, the difference between the observed and computed discharge at the time of forecast is maintained throughout the remainder of the simulation. Therefore, if your computed results are 100 cfs below the observed flow at the time of forecast, then you're going to maintain a difference of 100 cfs throughout the remainder of the simulation.

New Forecasting Alternative Capabilities

- **Automatic calculation of Initial Baseflow**
- **Automatic calculation of Initial Reservoir Elevations**
 - ▶ Allow for a reservoir elevation reset to the observed data at the start of forecast
- **Allow for only partial computes of watersheds (compute to point)**
- **Enhance the HEC-HMS plots to show data has changed and the results are not valid**



Initial Baseflow Editor

Forecast Initial Baseflow [SL_Francis] 33

Baseflow Zone: Upstream

Subbasins	Discharge Gage	Observed (CFS)	Minimum (CFS)	Maximum (CFS)	Default (CFS)	Ratio	Estimated Value (CFS)	Final Value (CFS)
B_LS01	Fredericktown	3.7	0	100000	10	1	3.7	3.7
B_BC02	Sam_A_Baker	99.0	0	100000	10	0.5261	52.1	52.1
B_BC01	Sam_A_Baker	99.0	0	100000	10	0.4739	46.9	46.9
B_SF08	Wappapello_Inflow	326.2	0	100000	10	0.1755	57.2	57.2
B_SF09	Wappapello_Inflow	326.2	0	100000	10	0.0935	30.5	30.5
B_SF10	Patterson	240.0	0	100000	10	0.1017	24.4	24.4
B_SF11	Saco	70.0	0	100000	10	0.2353	16.5	16.5
B_SF12	Milcreek	42.0	0	100000	10	0.3447	14.5	14.5
B_SF13	Roselle	9.5	0	100000	10	1	9.5	9.5

- The Initial Baseflow editor uses the baseflow zone configuration to assist in organizing data entry. The current zone is selected in the upper left corner of the editor. Each subbasin in the zone is shown on a separate row in the editor.
- A list of each subbasin within the selected zone is shown in this column.



Forecast Reservoir Editor

Forecast Reservoirs [St_Francis]

Discharge time-series data handling after forecast time for all reservoirs

Method: Replace Missing With Last

Set reservoir pool elevation from observed data

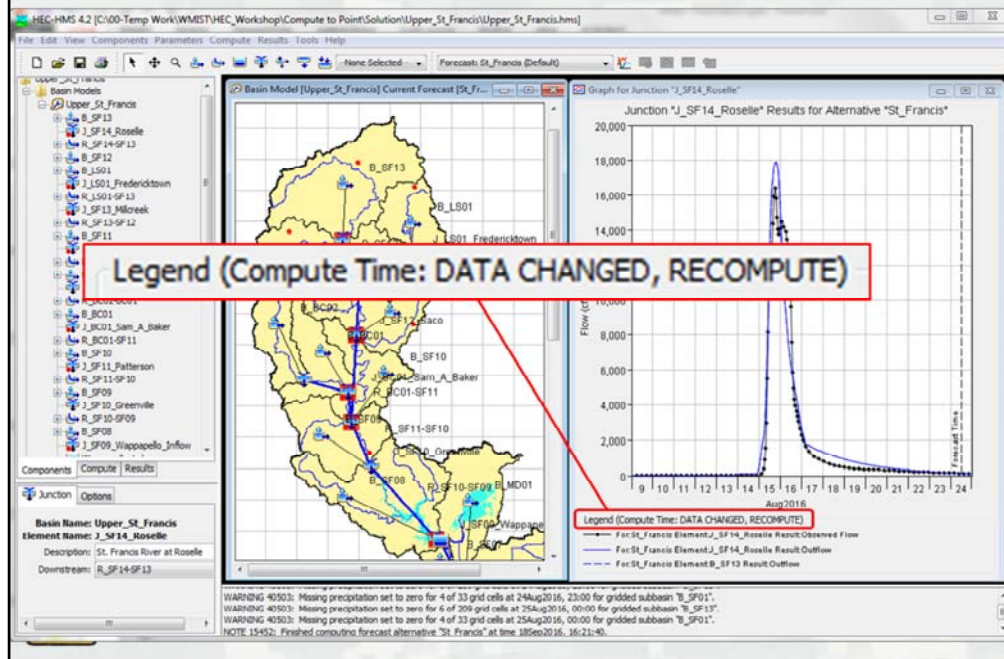
Reservoirs	Stage Gage	Observed (FT)	Minimum (FT)	Maximum (FT)	Default (FT)	Estimated Value (FT)	Final Value (FT)
Wappapello_Lake	Wappapello_Lake	361.3	350	420	359.7	361.3	361.3

Apply Reset Close

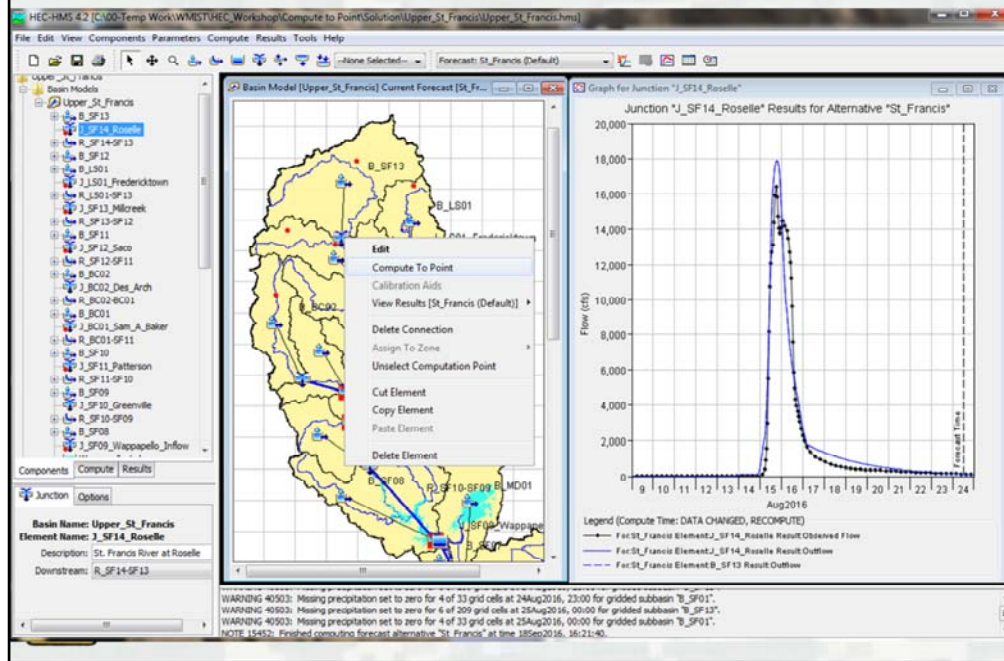
- The Forecast Reservoirs editor provides three choices for handling time-series data from the forecast time to the end time.
 - Replace any missing data after the forecast time with zero
 - Replace the missing data with the last available valid value.
 - Set all discharge values after the forecast time to zero regardless of whether they are missing
- The Forecast Reservoirs editor allows you to select a reservoir stage gage for each reservoir.
- At the Forecast time, the observed stage is used reset the reservoir elevation



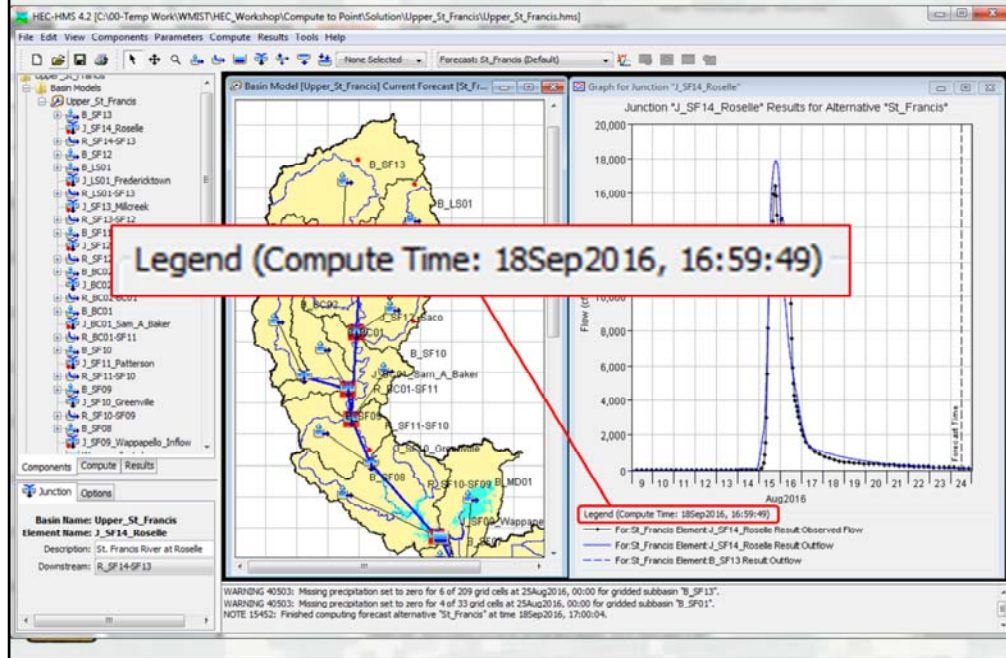
Compute and Plot Enhancements



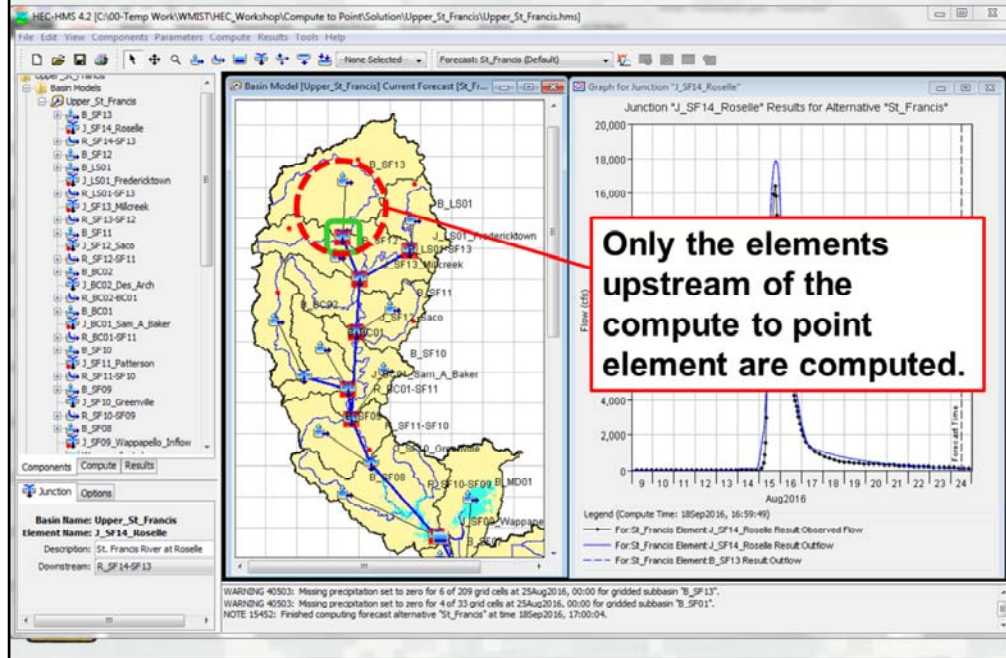
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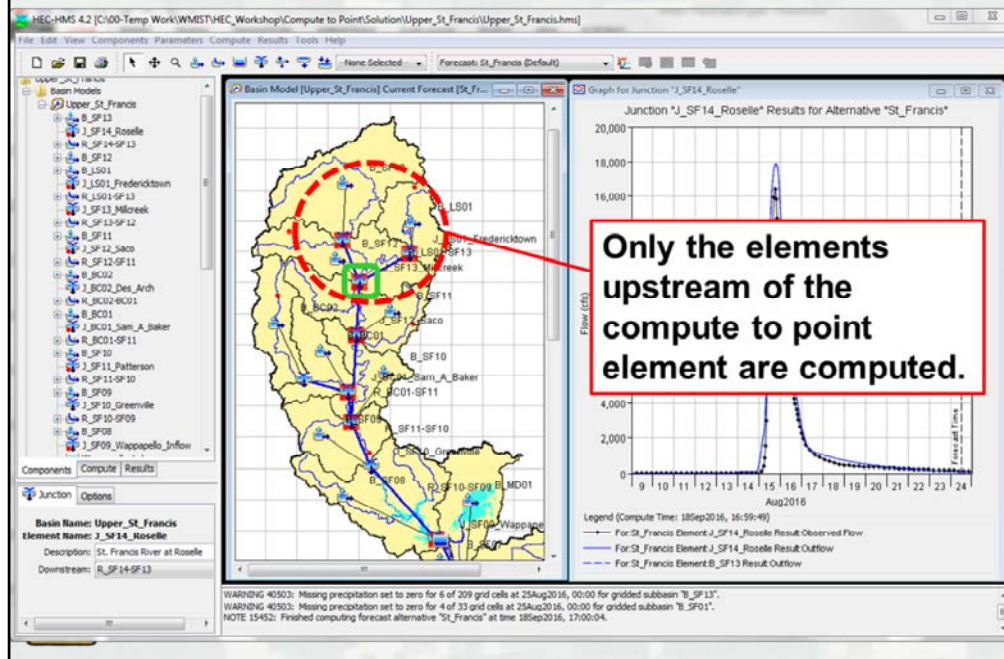
Compute and Plot Enhancements



Compute and Plot Enhancements



Compute and Plot Enhancements

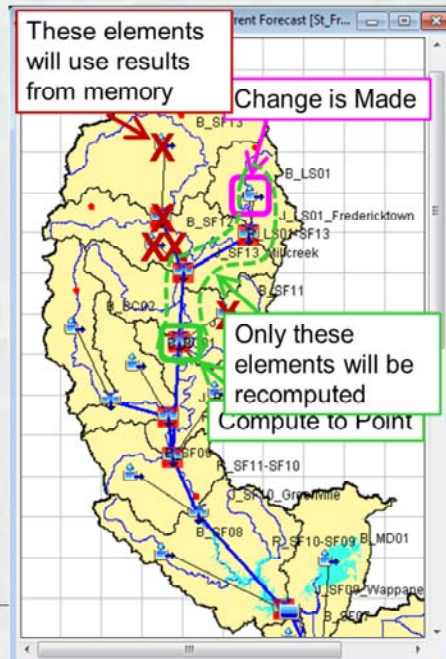


Additional Compute Efficiencies

- **Only the elements that have changed are recomputed.**
 - ▶ Dates of saved in the Basin Mod file are used for this enhancement
 - ▶ Results are stored in memory and are used for elements that have no changes.



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Additional Compute Efficiencies

Animated slide

Step by step of how an upstream element can be changed and a compute to point downstream will only recompute the changed element and the dependent elements to the compute to point element. All of the independent elements that have not changed will use results from memory.

Overview

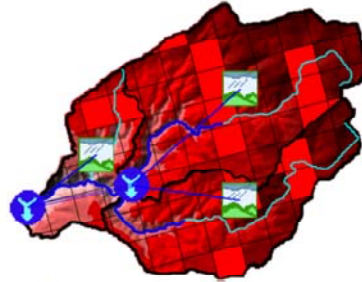
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 - ▶ Computational Efficiencies
 - ▶ Flood Forecasting Tools
- **Capabilities Under Development for HEC-HMS Version 4.3 and Beyond**
 - ▶ GIS Tools for Subbasin and Stream Delineation
 - ▶ Markov Chain Monte Carlo Optimization/Simulation
 - ▶ Variable Unit Hydrograph and Routing Options
 - ▶ Two-Dimensional Flow and Sediment



New GIS Capabilities

- HEC-GeoHMS has been used for 15+ years to develop the subbasin and reach delineations, and parameter information for an HEC-HMS project
- Significant decrease in time needed to develop a hydrologic model

HEC-GeoHMS Geospatial Hydrologic Modeling Extension



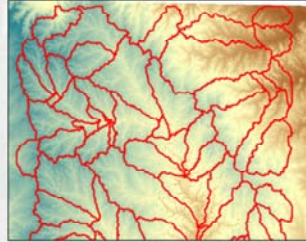
User's Manual



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New GIS Capabilities

- The GIS analysis capabilities available from HEC-GeoHMS are undergoing a major revision.
- Visualization of terrain data with color and shading.
- Automatic delineation of subbasin and reach elements directly from the terrain using an improved algorithm.
- Manual delineation of subbasin and reach elements.
- Creation of the grid cell file for use in gridded modeling methods.
- Eventually the spatial mapping will be integrated with subbasin time-series results and gridded results to produce colorized animations.



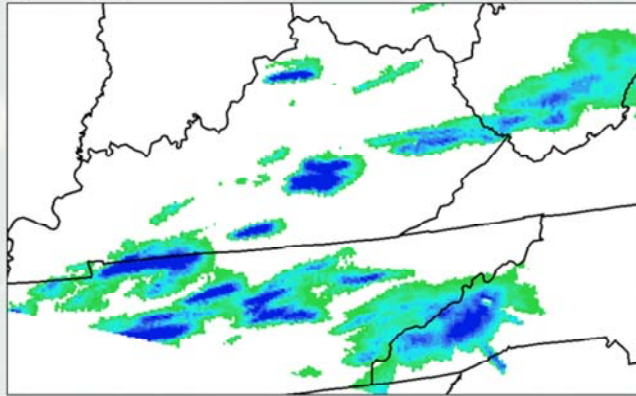
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- **Subbasin delineation tools are being added directly to HEC-HMS**
- **Import a GeoTiff terrain model and HEC-HMS will be able to delineate the subbasin and reach network.**
- **Identify outlet points and HEC-HMS will subdivide the subbasin and stream network.**
- **We are relying on TauDEM for automatic DEM processing.**

Raster Data

- Currently, gridded precipitation and gridded loss methods can only be applied within the US
- New capabilities are being developed for gridded modeling support using the UTM projection



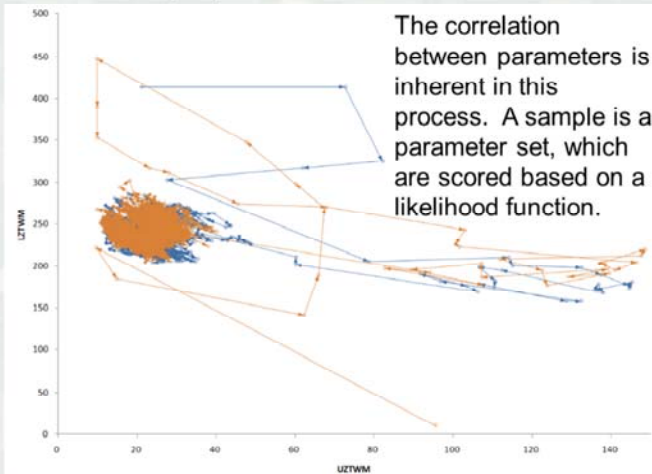
Bayesian Markov Chain Monte Carlo

Powerful new Uncertainty Analysis option that combines both model **calibration** and **uncertainty**.

The calibration phase refines the parameter uncertainty distributions by optimizing the model using observed discharge.

The refined uncertainty distributions can be used in subsequent model simulations, for hypothetical or historic storms.

Markov Chain (MC) directed random walk of the distribution.



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Run the chain to equilibrium (and this period is often referred to as the sampler *burn-in* period) and subsequently sample from its stationary distribution.
For a model of dimension size d (this might be an iterative process)

Specify a population size N – recommendation; N = an integer multiple of d ; $N=2$ or $N=2d$

Initialize, using Latin Hypercube sampling, the sampling process (and the population), with M_0 initial runs wherein M_0 is $\geq 10d$ – recommend more if doable

Evolve the population and use the Metropolis jumping rule to accept jump proposals

Use a weight of evidence based approach to assess that the sampler is sampling with stable frequency (i.e., it is reached equilibrium and hence is sampling from the posterior distribution)

efficiency curve

quantitative convergence diagnostic – necessary, but not sufficient condition

trace plots

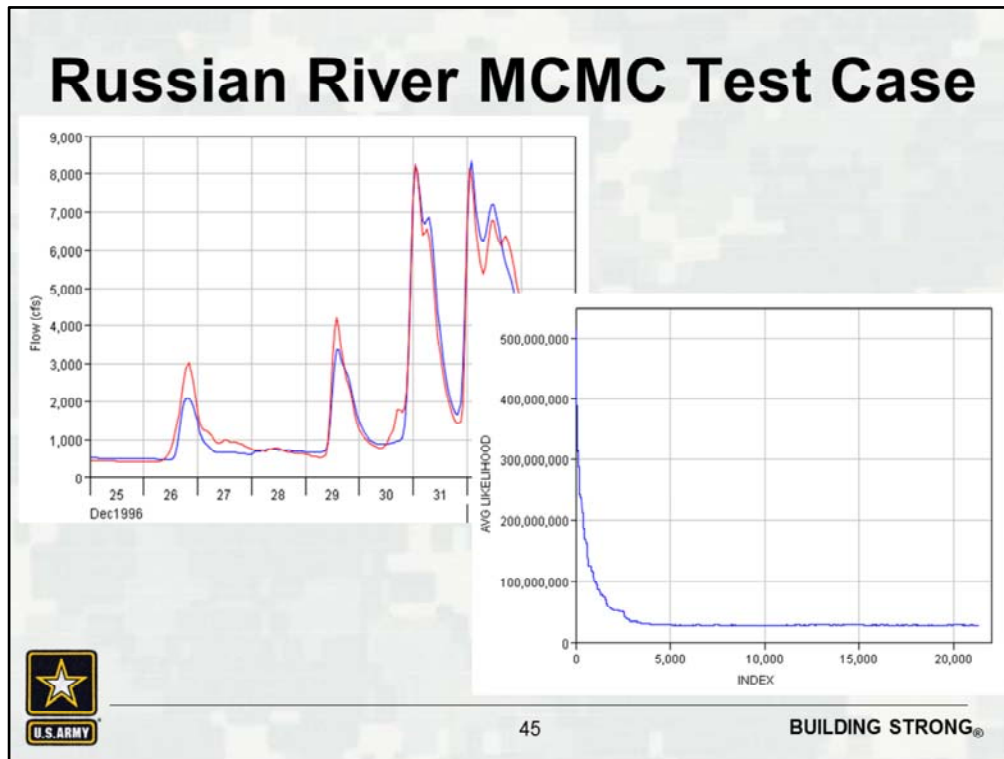
(manual user intervention – to support this)

Once “converged”, save a thinned history of the monitoring period draws and use them for inference

Russian River MCMC Test Case

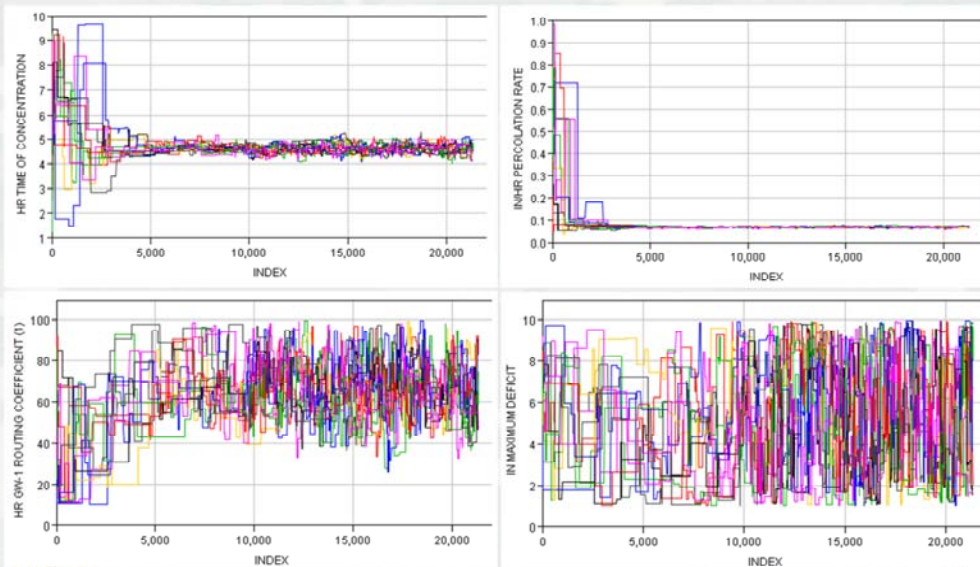
- The Russian River Forecast-Informed Reservoir Operations (FIRO) hydrology model was available for reuse as a test case of the Markov Chain Monte Carlo implementation in HEC-HMS.
- The event model examined the storm from 25 Dec 1996 to 2 Jan 1997.
- The continuous model examined the period from 1 Oct 2003 to 30 Sep 2004.
- The event and the continuous simulations cover time periods that are "typical" for this watershed.
- We focused on the area above Capella because there is good-quality observed flow and it is upstream of reservoirs that modify the flow regime.



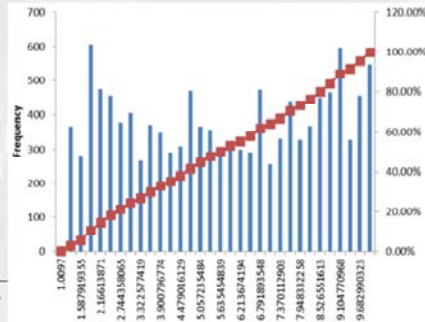
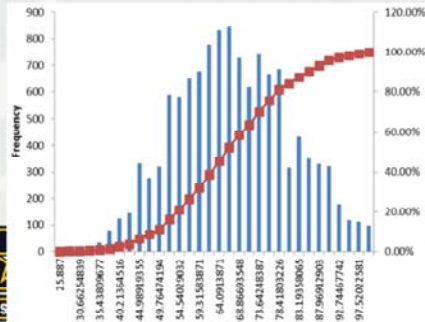
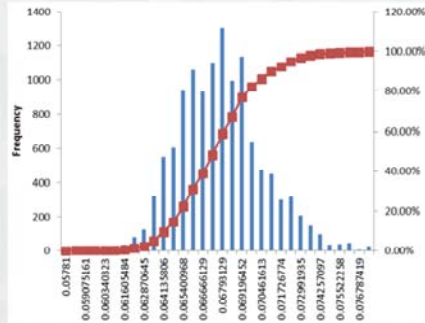
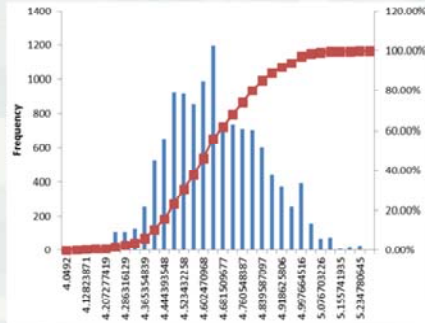


The figures on this slide show computed and observed flow at the end of the MCMC simulation. The “best” parameter set has been selected. The 20,000+ model simulations, across multiple chains, were required to reach the optimal parameters.

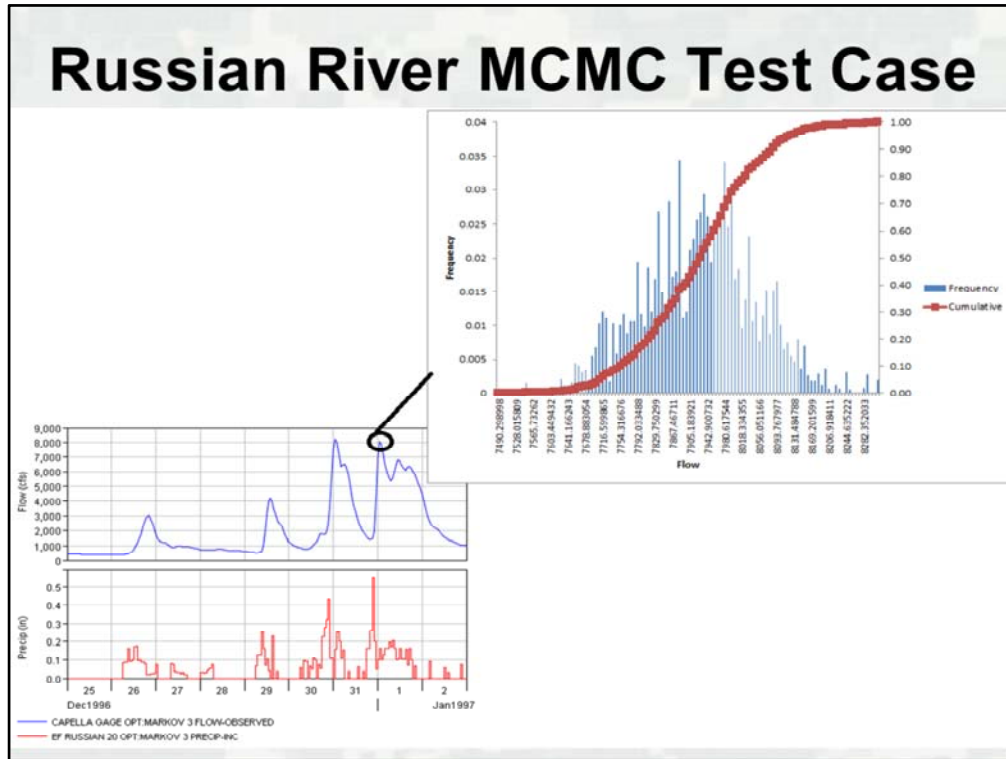
Russian River MCMC Test Case



Russian River MCMC Test Case

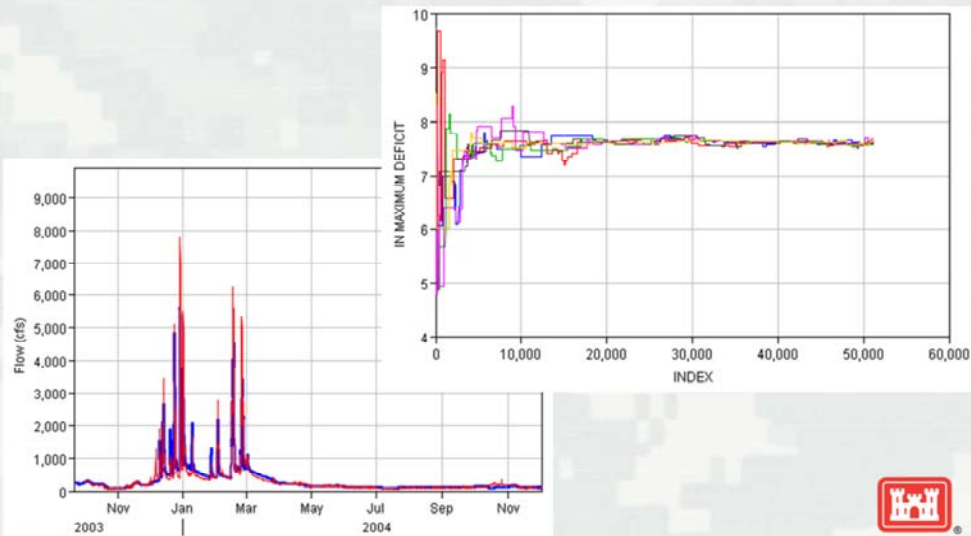


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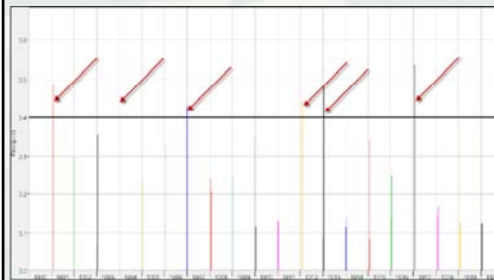
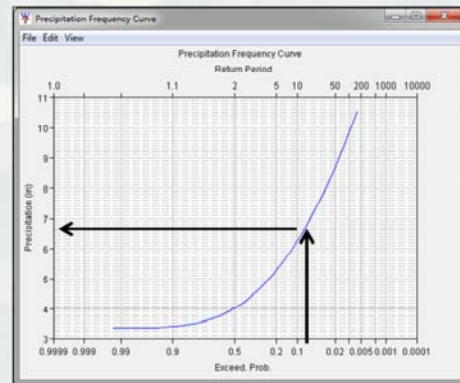
The figures show the distribution of peak flow from the MCMC simulation.

Russian River MCMC Test Case (continuous simulation)



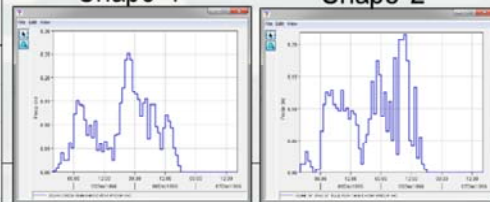
Uncertainty in Boundary Conditions

- Within HEC-HMS, boundary conditions stay the same from one sample to the next.
- HEC-WAT can be used to sample the event date, flow/precipitation magnitude, and time pattern.
- Subbasin hyetographs or flow hydrographs are scaled to reproduce the sampled storm depth before being passed to HEC-HMS.



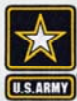
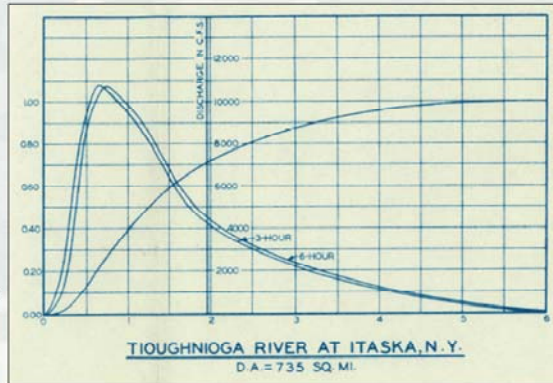
Shape 1

Shape 2



Unit Hydrograph Theory

- Originally proposed by L. K. Sherman in 1932
- Most commonly used method to transform excess precipitation to runoff at given locations
- Recommended for use across the world
- It's not going away...



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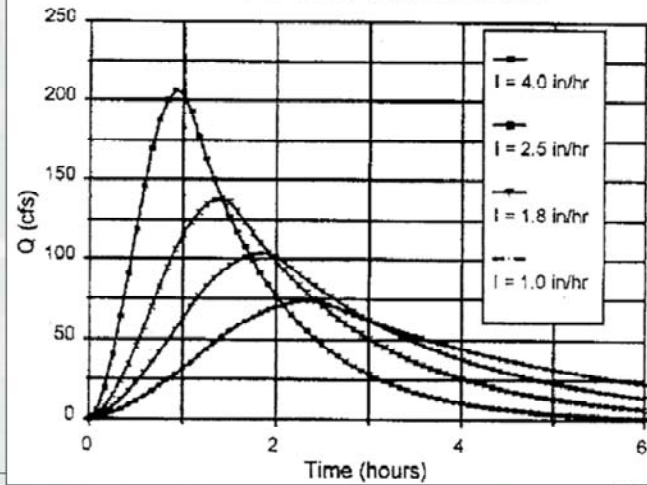
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- Unit hydrograph theory is the most commonly employed method within dam safety studies to transform excess precipitation to runoff at given locations in a dimensionless manner. In fact it's recommended for use throughout the world in dam safety studies.
- According to Sherman, 1932, who originally proposed the unit hydrograph concept, the unit hydrograph of a watershed is "...the basin outflow resulting from one unit of direct runoff generated uniformly over the drainage area at a uniform rainfall rate during a specified period of rainfall duration." This implies that the response of 2 inches of runoff over a given time is 2 times the response of 1 inches of runoff over the same amount of time.
- Unit hydrograph theory is still the state of the practice when it comes to hydrologic modeling. Take for instance analyses investigated parameter and modeling uncertainty: these often require many thousands of iterations that cannot be reasonably executed using more complicated runoff routing techniques. These analyses almost always are performed using unit hydrograph theory.

Unit Hydrograph Theory

Limitations

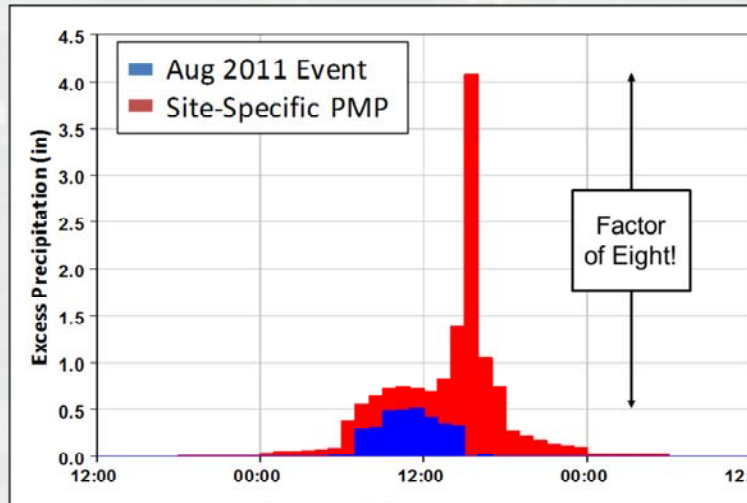
Varying Unit Hydrographs
Derived for Small Basin



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- However, due to differences hydraulic reactions between large and small precipitation events, the corresponding unit hydrographs have not been found to be equal, as implied by unit hydrograph theory.
- Minshall was one of the first people to explore the different runoff hydrographs that result from differing intensities of precipitation. The graph shown here is from his classic report in 1960. He showed that as precipitation intensity increases, runoff tends to peak sooner in time and has greater peak flow rates. This is due to greater depths in the stream channels and overland planes; as water depth increases, effective roughness decreases leading to shorter travel times, etc.

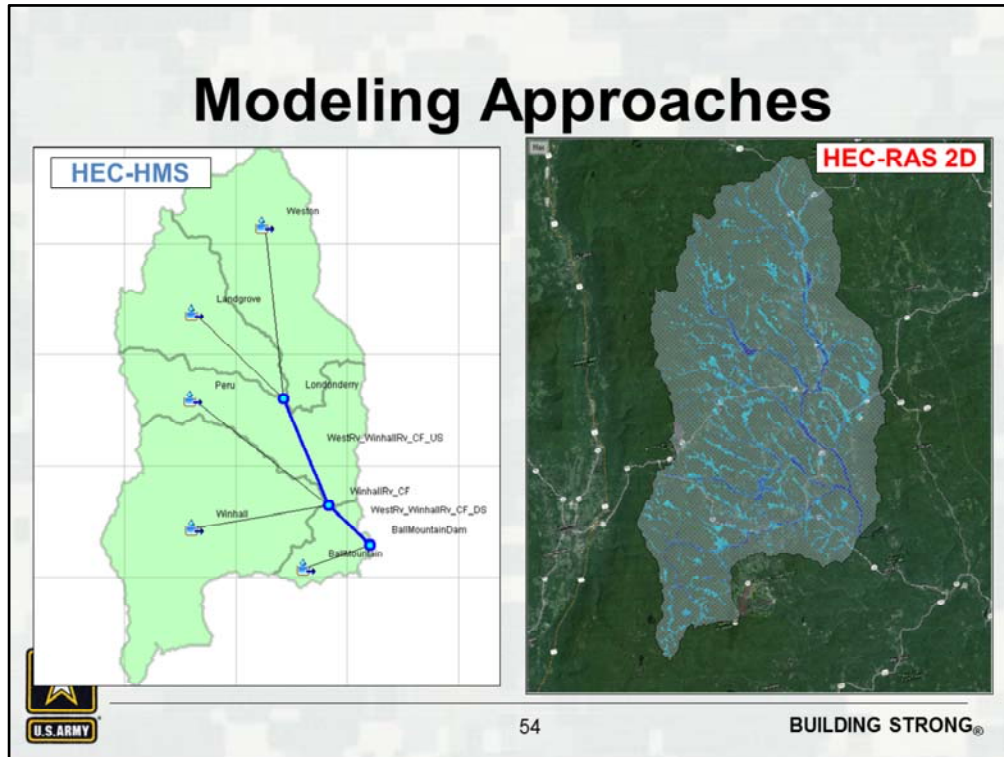
Unit Hydrograph Theory Limitations



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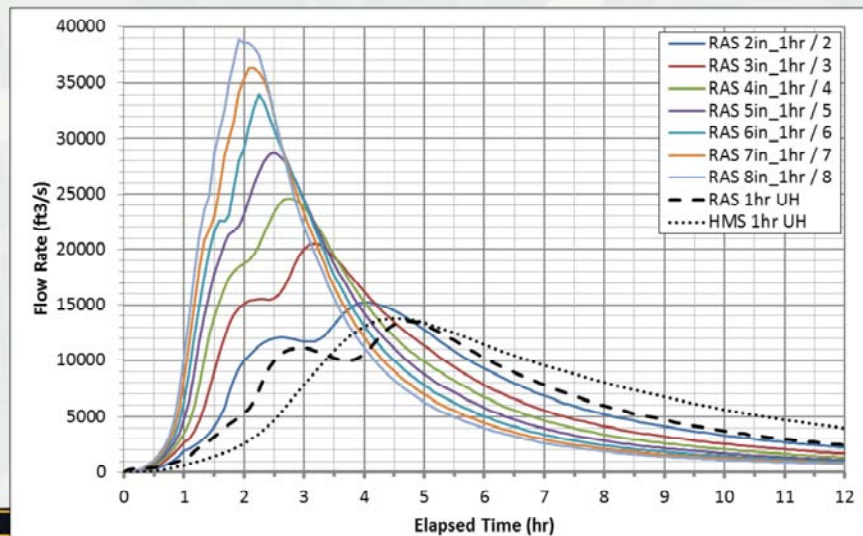
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- The amount of precipitation excess contained within the most intense precipitation event of recent history in the Ball Mountain Dam watershed absolutely PALES in comparison to the Probable Maximum Precipitation.
- Using calibrated unit hydrograph transform parameters from the Aug 2011 event (and really any other event that has available data) can lead to errors when trying to route excess precipitation on the order of 4 inches/hour.



- An HEC-HMS and HEC-RAS model were created for the area upstream of Ball Mountain Dam. Both models used the same modeling domain extents and were calibrated using the largest inflow events to Ball Mountain Dam.

Normalized One-Hour Storms



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- The effect of precipitation intensity on runoff timing and magnitude were evaluated using the previously mentioned HEC-RAS 2D model. Unit hydrograph theory assumes that the hydrograph ordinates of a 2 inch runoff event are two times larger than a 1 inch runoff event. This assumption of linearity can be evaluated using hydrodynamic models which include the physical processes that govern how water flows over the land surface.
- To demonstrate the non-linear effects of increasingly large rainfall excess values, two, three, four, five, six, seven, and eight inches of excess precipitation were input to the HEC-RAS 2D model over a unit duration (i.e. 1-hr). The overland roughness parameters from the Aug 2011 and Unit Hydrograph simulations were compiled using weighted averages to create a parameter dataset for use in these simulations. The resulting hydrographs were then extracted at the “outlet” cell faces just upstream of the Ball Mountain Dam reservoir. Each ordinate of the hydrographs was then divided by the input excess precipitation amount to “normalize” the runoff response.

Peaking Factors

Simulation	Peak Flow (cfs)	Time to Peak (hrs)	Volume (in)
HEC-RAS 1 hr UH	13553	4.8	1.0
HEC-RAS 2in 1hr / 2	15,245	4.0	1.0
HEC-RAS 3in 1hr / 3	20,522	3.2	1.0
HEC-RAS 4in 1hr / 4	24,636	2.8	1.0
HEC-RAS 5in 1hr / 5	28,728	2.5	1.0
HEC-RAS 6in 1hr / 6	34,055	2.3	1.0
HEC-RAS 7in 1hr / 7	36,338	2.2	1.0
HEC-RAS 8in 1hr / 8	38,879	1.9	1.0

Unit Hydrograph Peaking Factor for Excess Precipitation Rate (inches / hour)							
1	2	3	4	5	6	7	8
1.0	1.12	1.51	1.82	2.12	2.51	2.68	2.87

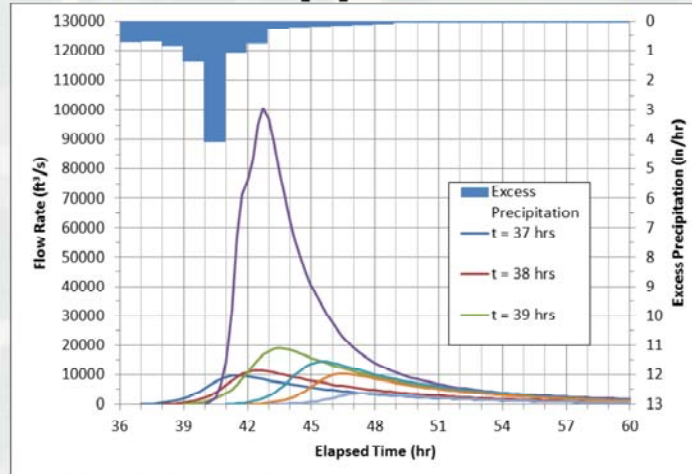


- If one were solely interested in predicting the peak flow rate of the PMF, it may be useful to compare the peak flow rates of the unit hydrographs and the normalized storm hydrographs estimated using the HEC-RAS 2D model. For instance, dividing the peak flow rate of the 2 inch/hour normalized storm by the HEC-RAS 1-hour unit hydrograph peak flow rate results in a ratio of 1.12. Similarly, dividing the peak flow rate of the 5 inch/hour normalized storm by the 1-hour unit hydrograph peak flow rate results in a ratio of 2.12.
- This table demonstrates that increasingly large unit hydrograph peaking factors are needed to achieve the same peak flow rate as the normalized storm depth (i.e. precipitation excess rate) increases. However, using excessively large unit hydrograph peaking factors may result in hydrologic modeling parameters that are physically unrealistic.

Variable UH Approach

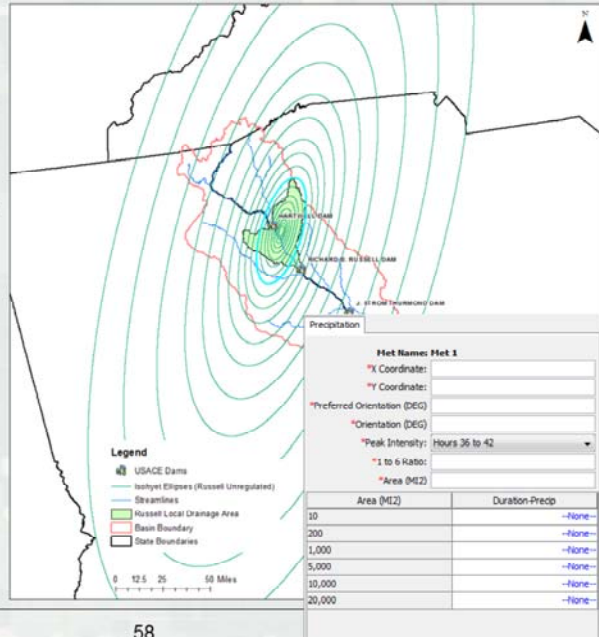
P _{excess} (in/hr)	T _c (hr)	R (hr)
0	5.3	5.5
0.5	5.1	5.5
1.0	5.0	5.3
2.0	4.1	5.0
3.0	3.4	3.5
4.0	3.0	2.8
5.0	2.7	2.3
6.0	2.5	1.8
7.0	2.5	1.6
8.0	2.3	1.5

Use information from observed data or 2D models to develop relationships between Excess Precipitation Intensity and Unit Hydrograph Parameters



Hypothetical Storms

- The *PMP Precipitation* method implements the HMR-52 storm pattern as a hyetograph for each subbasin.
- The user enters the coordinates for the storm centroid, rotation angle, and period of peak intensity.
- Subbasin outline coordinates are retrieved from an ESRI shape file.
- The storm pattern is intersected with the subbasin outlines and area-weighted average precipitation is computed for each subbasin.
- A *PMP Maximization* simulation is in development that will optimize runoff statistics:
 - Peak pool elevation.
 - Peak discharge rate.
 - Discharge volume.



Sediment Modeling in HEC-HMS

CHAPTER 8

Surface erosion and sediment routing studies

This chapter describes how to simulate watershed erosion and route sediment with HEC-HMS. HEC-HMS erosion and sediment transport model results can be a valuable resource in watershed management studies.

Background

Goals of erosion and sediment control

Modeling Surface Soil Erosion and Sediment Transport Processes in the Upper North Bosque River Watershed, Texas

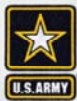
Jang Hyuk Pak¹; Matthew Fleming, Aff.M.ASCE²; William Scharffenberg³; Stanford Gibson⁴; and Thomas Brauer⁵

Abstract: A sediment transport module added to the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) Version 4.0 computes surface erosion, reach routing, and reservoir trap efficiency. The *HEC-HMS* sediment transport module was applied to the Upper North Bosque River Watershed (UNBRW) in central Texas, a well-instrumented watershed with good parameterization and calibration data, to test model robustness. The UNBRW is 98% rural including rangeland, forage, and dairy waste application fields. Simulation results were compared to observed average daily total suspended solid (TSS) data at five gauge locations. The *HEC-HMS* results matched observed



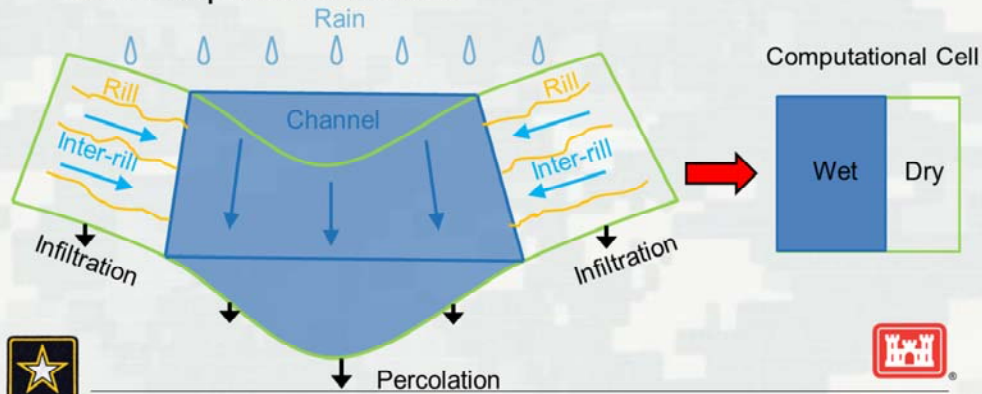
HEC-HMS 2D Sediment Transport

- 2D sediment transport in HEC-HMS
 - ▶ Sediment management is important to the Corps
 - ▶ Existing subbasin and 1D sediment transport capabilities in HEC-HMS
 - ▶ HEC-RAS 2D Diffusion Wave Equation (DWE) solver with subgrid bathymetry utilized for flow calculations
 - ▶ Opportunity to add 2D subgrid flow and surface erosion to HMS



Subgrid Modeling

- Representation of the physical terrain and processes at a subgrid scale
- Allows for larger grid cells reducing computational cells, and computational times



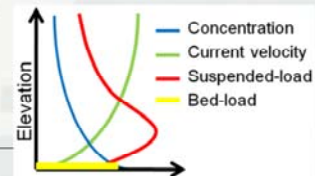
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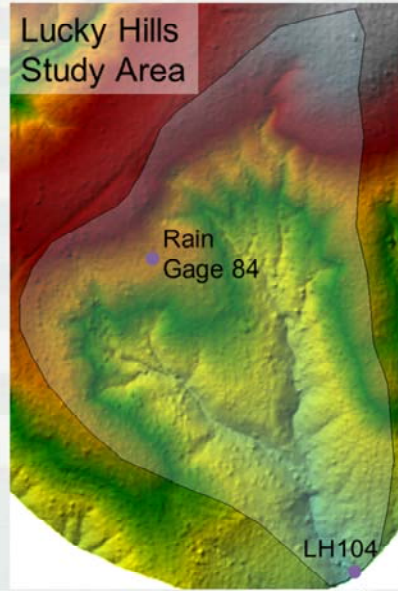
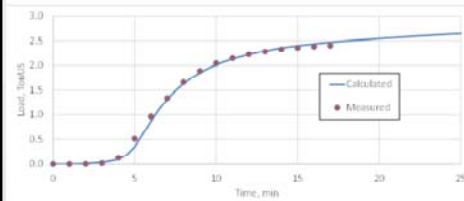
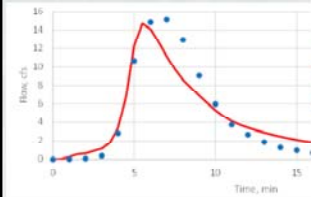
Sediment Transport

- Governing Equations
 - ▶ Total-load advection-diffusion equation
 - ▶ Bed change, sorting, and layering equations
- Numerical Methods
 - ▶ Implicit Finite Volume
 - ▶ Several bounded high-order advection schemes
- Key Features
 - ▶ Sheet and splash erosion
 - ▶ Non-equilibrium transport
 - ▶ Subgrid representation of bed sorting, layering, bed forms, hiding and exposure, erosion rates, etc.
 - ▶ Mixed cohesive and noncohesive sediments
 - ▶ Particle-particle interactions
 - ▶ Avalanching, non-erodible surfaces, etc.



Pilot Study: Lucky Hills Study Site

- USDA Walnut Gulch Experimental Watershed
- Area: ~1 ac
- Sandy Loam



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Additional New Capabilities

- Variable Lag and K routing method
- Additional new routing methods that include cross sections and diffusion wave routing
- Update to the computation code to solve for all space for each time step – improve memory management and help set up additional capabilities
- Reservoir routing for downstream locations
- Energy balance snowmelt and frozen ground modeling
- Green and Ampt infiltration with moisture re-distribution for continuous simulation



HEC-HMS

Software And Documentation
Are Available Free of Charge

www.hec.usace.army.mil/software/hec-hms

